OPTIMIZED ROTARY FLUX COMPRESSORS FOR POWERING LASER FLASHLAMPS*

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Introduction

Very large rotary flux compressors provide one means to power large laser systems in the future. These machines are the only devices that have the demonstrated ability to convert rotating inertial energy into high power, millisecond electrical pulses.

We have studied the active rotary flux compressor (ARFC) with a code developed by Eimerl and Goodwin at LLNL from work originated at UT, Austin.[1] The purpose was to evaluate the cost effectiveness of the ARFC's for use in powering flashlamps that pump Nd-glass laser amplifiers.

In general, the larger the machine, the less its specific cost (i.e., cents per joule, or dollars per kilowatt). Because of this, emphasis was placed upon large-size machines. Size limitations do exist, however. For example, in very large drum-type ARFC's the mass may scale nearly as d^3 (where d is the rotor diameter), but the maximum power output scales as d^2, because power is taken out as shear over the rotor surface area.

We found that a practical limitation on machine size is established by the 42-inch maximum available width of sheet silion steel. Because both the rotor and stator of the ARFC are constructed from insulated and stacked disks of this material, the maximum outer dimension must be 42 inches unless one is willing to segment the stator. But even with a segmented stator, the rotor diameter must not exceed 42 inches unless it too is segmented.

Because of the strength penalty paid by segmentation of the rotor, we determined that the largest practical ARFC would be an optimized machine with a 42-inch diameter rotor. We also calculated the optimum 42-inch OD machine with a non-segmented stator because this machine is simpler to construct. This smaller machine was found to be cost effective, even though it produces only 38% of the energy output of the larger device.

Summary

Two ARFC's were optimized with the LLNL code. The "large" machine had a 42-inch diameter rotor. It provided 14 MJ of energy to a flashlamp load in a 900 μsec, 16 GW pulse. Its mass was 30 tonnes.

The "small" machine provided a peak power of 8 GW in a 590 μsec pulse, and delivered 5.4 MJ to the flashlamp load. Its mass was 13 tonnes. The parameters of these optimized machines are summarized in Table 1. Both of these devices were 8 pole ARFC's with two turns per pole.

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Circuit

The ARFC's require startup current that establishes the initial flux in the machine at the time of maximum inductance. In the model, this current is provided with a capacitor bank. The circuit is the same as that used for a previous test of a small ARFC[2,3], Figure 1. In a large system, the bypass diode would be replaced with a triggered switch that would handle the high peak current out of the device.

Constraints

A number of constraints are established in the program so that physical limits are not exceeded. We have already discussed the 42-inch constraint for the rotor diameter. This establishes a maximum rotor length, because the maximum length to diameter ratio is constrained by vibration and rotor tip-speed considerations. Since the power output is proportional to tip speed, a high value is desired: A limit of about 150 meters per second has been established as the estimated maximum safe speed.

The first critical rotor frequency of vibration was calculated from the estimated stiffness of the laminated package. The maximum rotor length was established by making this frequency 9% higher than the RPM that provides 150 m/sec tip speed.

Other constraints included conductor heating ($\Delta T < 25^oC$), startup capacitor voltage (25 kV) and width of the current pulse (1 msec FWHM). A principal limiting constraint in the program was the shear strength of the insulating bond between the rotor laminations and the winding conductors. This constraint, together with the tip speed, establish the peak power available from a given-size machine. It was set at a somewhat optimistic 4000 psi (27.6 MPa).

Table 1. Parameters of optimum 8 pole, 2 turns/pole drum-type Active Rotary Flux Compressors

	Large Machine 42" Dia Rotor	Small Machine 42" Dia Stator
Equivalent capacitor energy (MJ)	14.4	5.4
Start-up capacitor energy (MJ)	2.1	0.8
Rotor mass (Tonnes)	15.2	6.8
Machine mass (Tonnes)	29.5	13.3
Specific energy (J/kg)	489	406
Specific power (kW/kg)	539	600
FWHM current pulsewidth (μsec)	897	589
Peak flashlamp power (GW)	15.9	8.0
Average shear stress (MPa)	26.7	27.0
RPM	2706	3600
Tip speed (m/sec)	151	151
Number of poles	8	8
Number of conductors per pole	2	2

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Variables

Calculations were made for machines with 4,6,8,10, and 12 poles. The number of conductors per pole was varied from one to five.

Performance Measures

The optimum machines for each element of the matrix of variables were calculated. The measures used in the judgment of optimum performance included:

1. The equivalent capacitor energy: i.e., the capacitively stored energy that would be needed to replace the ARFC for driving flashlamps in the Nd-glass laser pumping application;

2. The energy in the startup capacitor;

3. The peak power at the machine terminals; and

4. The specific energy (J/kg) and power (kW/kg) of the machine, calculated by estimating the total mass of the machine (excluding peripheral equipment).

Results

Large Machine

The optimum ARFC with a 42-inch diameter rotor and a segmented stator had 8 poles, with two windings per pole, or a total of 16 turns through the machine. (The technique of supplying one pole with a missing turn so that the conductors need not cross over each other was not employed here; however, the results are about the same in either case.) A machine with 6 poles and 3 turns per pole provided 11% more total energy but the pulsewidth became too long. The 10 pole x 2 turns/pole ARFC provided 16% higher specific power, but it only supplied 91% of the total energy. Comparisons of these three machines are given in Table 2.

The optimum 8P/2T ARFC could drive all of the flashlamps in 24 of the large 46-cm aperture amplifiers for the Nova Nd-glass laser. Each of these amplifiers is presently supplied with a 600 kJ capacitor bank.

Table 2. Relationships between optimum large ARFC's (Relative to the 8P/2T machine)

	6P 3T	8P 2T	10P 2T
Relative total energy	1.11	1.00	0.91
Relative specific energy	0.93	1.00	1.02
Relative peak power	0.90	1.00	1.03
Relative specific power	0.77	1.00	1.16
Startup energy/total energy	0.15	0.16	0.17

Small Machine

The optimum "small" ARFC, with 42-inch overall (stator) diameter was also an 8-pole, 2 turns per pole machine (16 total turns). Comparisons between this machine and its nearest rivals are given in Table 3. This optimum machine could drive the flashlamps in 9 of the 46-cm Nova amplifiers.

Table 3. Relationships between optimum small ARFC's (Relative to the 8P/2T machine)

	6P 3T	8P 2T	10P 2T
Relative total energy	0.87	1.00	0.89
Relative specific energy	1.21	1.00	1.05
Relative peak power	0.56	1.00	0.86
Relative specific power	0.82	1.00	1.13
Startup energy/total energy	0.16	0.14	0.16

Comparison Between Large and Small ARFC's

The parameters of the two optimum ARFC's have been summarized in Table 1. The output current into a flashlamp load is presented in Figure 2 for both devices. The power at the terminals of each machine is given in Figure 3.

From this study, it is not clear that the larger machine will be more cost effective than the smaller. Our studies do indicate, however, that both ARFC's will be about on par with the lowest cost capacitive system for single-shot applications such as the Nova laser. Thus no real need exists for a single-shot ARFC.

We believe that future incentive for ARFC development will come from programs requiring large rep-rated pulsed power systems. The machine appears ideally suited to provide both burst-mode and continuous duty repetitive pulses of high energy, with pulsewidths between 100 μsec and 10 msec.

At this time, we would favor development of an ARFC of a size similar to the smaller of the two machines of this study. In other words, we prefer a device in which both the rotor and the stator laminations could be stamped from a single sheet of steel. Such a machine would weigh about 30,000 pounds, and it could be transported by conventional means.

References

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2. B. Carder, D. Eimerl, E. J. Goodwin, J. Trenholme, R. J. Foley, "Testing and Optimizing Active Rotary Flux Compressors", 3rd IEEE Pulsed Power Conference, pp 304-307.

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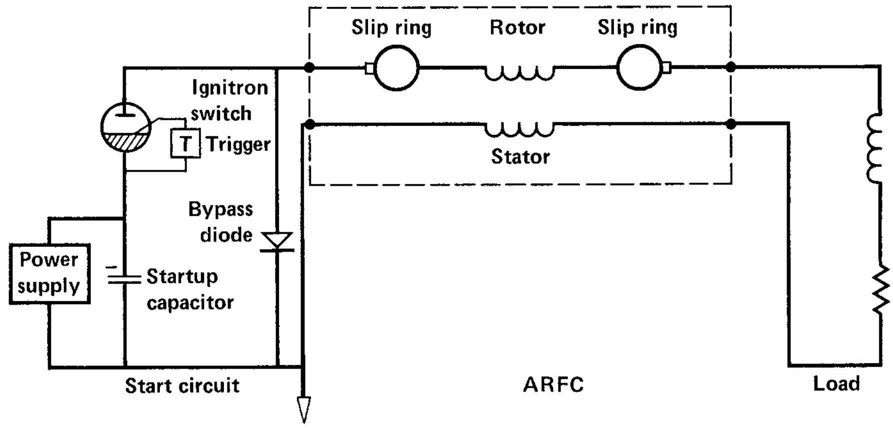

Figure 1. Active Rotary Flux Compressor Test Circuit

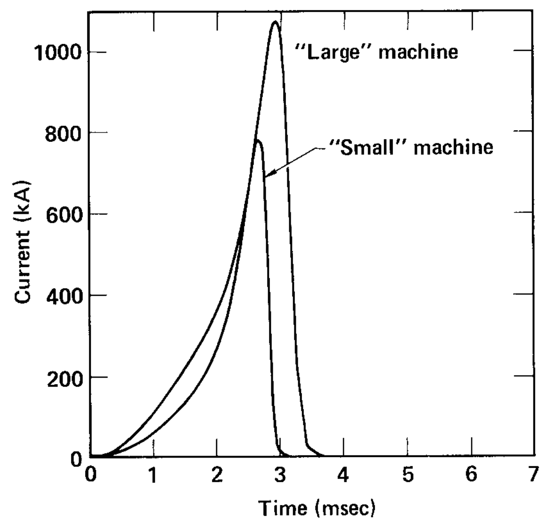

Figure 2. ARFC Machine Current

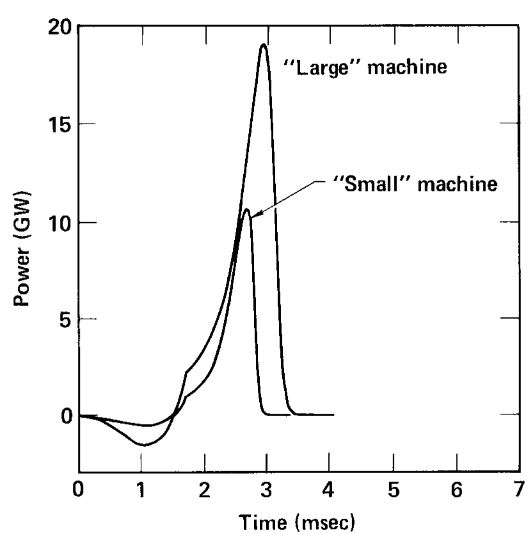

Figure 3, Power at Machine Terminals